THE EFFECT OF MATCHING WATERMARK AND COMPRESSION TRANSFORMS IN COMPRESSED COLOR IMAGES

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ABSTRACT

The growth of networked multimedia systems has complicated copyright enforcement relative to digital images. One way to protect the copyright of digital images is to add an invisible structure to the image (known as a digital watermark) to identify the owner. In particular, it is important for Internet and image database applications that as much of the watermark as possible remain in the image after compression. Image adaptive watermarks are particularly resistant to removal by signal processing attacks such as filtering or compression. Common image adaptive watermarks operate in the transform domain (DCT or wavelet); the same domains are also used for popular image compression techniques (JPEG, EZW). This paper investigates whether matching the watermarking domain to the compression transform domain will make the watermark more robust to compression.

1. INTRODUCTION

Many watermarking schemes have been introduced for digital images; spatial and transform domain techniques are the most common. Spatial techniques generally adjust the lower-order bits of image pixels to guarantee imperceptibility [1]. Spectral or transform techniques incorporate the watermark into the transform coefficients of an image [2]. Popular transforms include the discrete cosine transform (DCT) and the wavelet transform. Transform-based algorithms allow one to easily place the watermark in the perceptually *significant* parts of an image; this leads to a mark that is more robust to attack, since it is harder to remove without distorting the image [2]. Since image-adaptive (IA) watermarks not only reside in the significant parts of an image, but also adjust their amplitude to the image being marked, they withstand signal processing attacks particularly well [3].

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An effective watermark must withstand image compression, because images placed on the Internet or in databases are almost always compressed – sometimes to a very low data rate. Since compression tends to weaken a watermark in an image, it is important to find ways to maximize the amount of watermark that remains in the image after compression. In this paper two color image compression algorithms will be examined: JPEG, which uses the DCT, and a wavelet-based algorithm known as *Color Embedded Zero-Tree Wavelet (CEZW)* compression [4,5,6]. Two image-adaptive watermarking techniques known as IA-DCT and IA-W [7,8] will be compared. IA-DCT marks an image in the DCT domain, where IA-W uses the wavelet domain. It is the goal of this paper to determine if using the same domain for both watermarking and compression will preserve more of the watermark for a given data rate. For instance, if two versions of an IA-DCT watermarked image are compressed at the same data rate – one with JPEG, the other with *CEZW* – is the watermark more easily detected in the JPEG image?

First the two watermarking schemes are described, after which a brief description of JPEG and *CEZW* is presented. Test images are then watermarked with both techniques. These images are then compressed with JPEG to 1.5 and 0.5 bits per pixel (bpp). The decompressed images are then tested to see which watermark (IA-DCT or IA-W) more effectively remained in the image. This experiment is repeated with *CEZW.*

2. THE IA WATERMARKS

The image-adaptive watermarks are based on the robustness of the basic spread-spectrum technique in [2]. The work in [8] shows that using visual models in the watermark embedding scheme can produce an even more robust watermark than [2]. Specifically, visual models allow the user to raise or lower the amplitude of the watermark according to the image content (hence the name, image-adaptive). These visual models provide thresholds for how much a given transform coefficient can change, before such changes are noticeable under standard viewing con-

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ditions. These thresholds are known as *just-noticeable difference (JND)* values. The larger the JND values, the more coarsely a coefficient can be quantized without noticeable visual distortion. In the same way, larger JND values allow us to imperceptibly add a larger-amplitude watermark to the transform coefficients. More information on the development of the DCT and wavelet JND values can be found in [7,8].

The general IA technique is described below. This technique embeds a normally distributed zero mean pseudorandom sequence into the coefficients (DCT or wavelet) of an original luminance image X. The transform of the image X is first obtained to form $X_{u,v}$, where u and v are the transform domain indices. The coefficients for the marked image Y are formed as follows:

$$Y_{u,v} = \begin{cases} X_{u,v} + W_{u,v} J_{u,v}, & |X_{u,v}| > J_{u,v} \\ X_{u,v}, & \text{otherwise} \end{cases} \quad (1)$$

$W_{u,v}$ is the watermark element and $J_{u,v}$ is the *just-noticeable-difference* value for the particular transform coefficient. $J_{u,v}$ scales $W_{u,v}$ to ensure that the value added to $X_{u,v}$ is as large as possible, while still remaining invisible. The inverse transform of $Y_{u,v}$ forms the marked image Y.

To verify a (possibly altered) marked image Z, one first obtains the normalized correlation coefficient (the test statistic) between the watermark W and the version of the watermark extracted from Z. The extracted version of the watermark is W^*.

$$W_{u,v}^* = \frac{X_{u,v} - Z_{u,v}}{J_{u,v}} \quad (2)$$

$$\rho = \frac{W \cdot W^*}{W^* \cdot W^*} \quad (3)$$

$$\begin{array}{ll} \rho > T & Z \textit{ authentic} \\ \rho \le T & Z \textit{ not authentic} \end{array} \quad (4)$$

If W and W^* are completely different, ρ will be normally distributed with zero mean and very small variance. If W^* is a mildly damaged version of W, ρ will be near 1. $T \in (0,1)$, and is a user-defined threshold based on the desired probability of watermark detection (PD) and probability of false alarm (PFA).

The IA-DCT test produces a single ρ, which is used as the test statistic. The IA-W testing procedure is performed on a band-by band basis, which produces a different ρ for each band. We would like to choose the IA-W test statistic as a function of these values in such a way as to maximize the mark's resistance to attacks. Two facts will affect our decision:

1) Certain image processing operations will affect some bands much more than others. For instance, low pass filtering will damage the higher resolution bands more than the low resolution ones.
2) Certain images may have a lot of energy in a particular wavelet orientation. A city-scene, for instance, would have many horizontal and vertical structures, but weak diagonal features. In such an image the wavelet coefficients (and therefore the watermark amplitude) could be much larger in the horizontal and vertical bands than the diagonal ones.

To take advantage of both effects, we will use the maximum ρ over all subbands as the IA-W test statistic. In this way we have some protection against attacks that leave at least one subband relatively undisturbed. We also take advantage of any built-in image structures that are favorable to storing large-amplitude watermarks.

3. COLOR IMAGE COMPRESSION

The two types of color image compression used in our study are JPEG and *CEZW*. JPEG compression first segments an image into 8 x 8 blocks, and computes the DCT of each block. The DCT coefficients are then quantized, then source coded to form the compressed bitstream. A quantization table that is specified as an input to the encoder gives the quantizer step size that is used for each coefficient. JPEG compression is fully described in [9].

Shapiro [10] proposed a wavelet-based image compression technique known as the Embedded Zero-Tree Wavelet algorithm (EZW). EZW exploits the unique nature of the wavelet transform to describe a tree-like structure and a successive-refinement quantization scheme for the wavelet coefficients. The advantage of this technique is that the compressed data stream contains information in the order of its perceptual significance. The decoding of the compressed data stream may be halted at any time to meet data rate constraints. An extension to color images known as *Color Embedded Zero-Tree Wavelet (CEZW)* compression is presented in [4,5,6]. In *CEZW*, the tree structure is first obtained for each color component. Then a single tree structure is formed which incorporates the component trees. Quantization and refinement of the coefficients are performed using the new tree. The reader is referred to [4,5,6] for the details of *CEZW*.

IA-W and *CEZW* both use the 9-7 biorthogonal filters to transform the image into the wavelet domain; IA-DCT and JPEG both use the DCT. The experiments below investigate whether matching the transforms used for watermarking and compression will degrade the watermark less than if different transforms are used.

4. EXPERIMENTAL PROCEDURE

To determine the effects of matching the watermarking domain to the compression domain, the following experiments were performed:

1. An original 24-bit color image, X, was transformed into the YUV color space, and the luminance plane was marked according to IA-DCT. The marked image is called Y_D. A second copy of X was then marked with IA-W to form Y_W.
2. Both Y_D and Y_W were JPEG compressed and decompressed at 1.5 bpp to form Y_{DD} and Y_{WD} respectively. (The first subscript corresponds to the watermarking domain, and the second corresponds to the compression transform.)
3. Y_D was also compressed with *CEZW*, then decompressed at 1.5 bpp to form Y_{DW}. This was repeated with Y_W to form Y_{WW}.
4. The four compressed images were then tested for the presence of the watermark with their respective algorithms.
5. This process was performed for three different images: fruit, girls, and peppers.
6. The experiment was repeated for 0.5 bpp.

5. EXPERIMENTAL RESULTS

The test statistics obtained from the above experiments are shown in Table 1. It was expected that for IA-DCT marked images, the JPEG compressed pictures would yield larger test statistics than the *CEZW* compressed ones. The *CEZW* compressed images actually produced larger test statistics than the corresponding JPEG images, although the differences were relatively small. As expected, *CEZW* yielded larger test statistics than JPEG for IA-W images; this difference is most noticeable at 0.5 bpp.

Table 1. Watermark test statistics.

Image	IA-DCT marked images			
	1.5 bpp		0.5 bpp	
	JPEG	CEZW	JPEG	CEZW
Fruit	0.88	0.95	0.46	0.56
Girls	0.87	0.96	0.57	0.59
Peppers	0.93	0.96	0.6	0.7
	IA-W marked images			
Fruit	1.0	1.0	0.10	0.94
Girls	0.80	1.0	0.12	0.91
Peppers	0.88	1.0	0.16	0.92

Figure 1 shows the test statistics for the IA-DCT images. The 1.5 bpp images have test statistics close to one, while the 0.5 bpp images have an average test statistic value of 0.6. This is a much more graceful degradation of the watermark than shown in Figure 2, which shows the IA-W data. Here the 0.5 bpp JPEG compressed IA-W image has practically no trace of the watermark (test statistic = 0.1). However, the 0.5 bpp *CEZW* compressed images have test statistics comparable with the 1.5 bpp images (test statistic = 0.9).

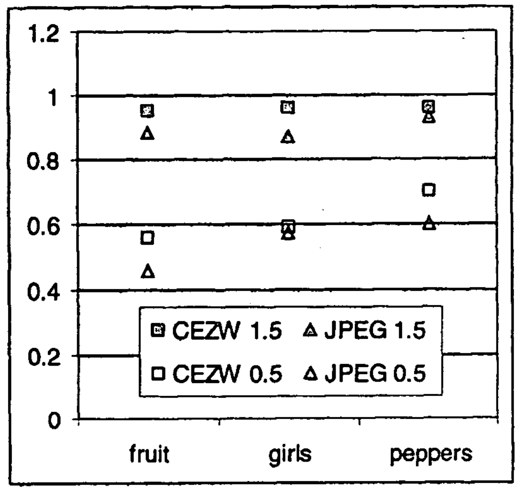

Figure 1. Test statistics for IA-DCT images.

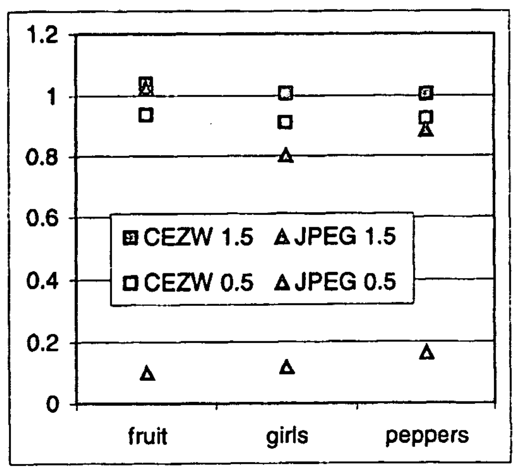

Figure 2. Test statistics for IA-W images.

Figure 3 shows the IA-W watermarked fruit image at the top, the IA-W watermark in the center, and the IA-DCT watermark at the bottom. Figure 4 and Figure 5 show the results from the girls and peppers images respectively. The IA-W marked images were visually indistinguishable from the original images, and are shown here for illustrative purposes only. The IA-DCT marked images were not in-

cluded because they were also perceptually identical to the originals.

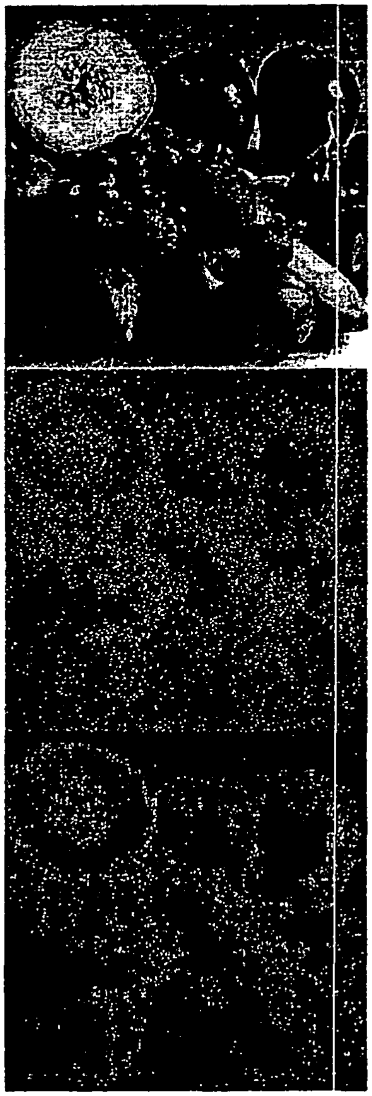

Figure 3. Top: image marked with IA-W; center: the IA-W watermark; bottom: the IA-DCT watermark.

6. CONCLUSION

Based on our experiments, we find that at low data rates it is beneficial to match the transform framework of the watermarking scheme to the transform framework of the compression scheme. At high data rates, matching the transforms is not critical. We also observe that the CEZW scheme also results in better watermark detection for either watermarking scheme (not only the wavelet-based scheme). This is due in part to the fact that since the original image quality is better preserved using this compression algorithm, the watermarks – which are highly correlated to the original image content – are also better preserved. At the lower bit rate (0.5 bpp), the correlation values are quite low for the JPEG compressed IA-W images, but this may not be critical if the compression artifacts at this bit rate destroy the original image quality.

Figure 4. Top: image marked with IA-W; center: the IA-W watermark; bottom: the IA-DCT watermark.

Figure 5. Top: image marked with IA-W; center: the IA-W watermark; bottom: the IA-DCT watermark.

An Adobe PDF version of this paper, and the images are available via anonymous ftp to **skynet.ecn.purdue.edu** in the directory **/pub/dist/delp/icip98-wmark.**

7. REFERENCES

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